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Biomimetics and the development of humanlike robots as the ultimate challenge

Yoseph Bar-Cohen, Jet Propulsion Laboratory, California Institute of Technology
http://ndeaa.jpl.nasa.gov

ABSTRACT

Evolution led to effective solutions to nature's challenges and they were improved over millions of years. Humans have always made efforts to use nature as a model for innovation and problems solving. These efforts became more intensive in recent years where systematic studies of nature are being made towards better understanding and applying more sophisticated capabilities. Making humanlike robots, including the appearance, functions and intelligence, poses the ultimate challenges to biomimetics. For many years, making such robots was considered science fiction, but as a result of significant advances in biologically inspired technologies, such robots are increasingly becoming an engineering reality. There are already humanlike robots that walk, talk, interpret speech, make eye-contact and facial expressions, as well as perform many other humanlike functions. In this paper, the state-of-the-art of humanlike robots, potential applications and issues of concern will be reviewed.

Introduction

Through evolution effective solutions have been introduced to nature's challenges and the solutions were improved over millions of years. Recognizing their value, humans have always made efforts to use nature as a model for innovation and problems solving. These efforts intensified in recent years and significantly more sophisticated capabilities have been developed [Vincent, 2001; Bar-Cohen, 2005]. The field, which is now known mostly as biomimetics, has become a science and engineering field of seeking to understand and use nature as a model for copying, adapting and inspiring principles, concepts, mechanisms, and designs. As a result, manufacturing, materials, processes, and algorithms have been developed and implemented to produce effective structures, actuators, sensors, interfaces, control, software, drugs, defense, intelligence and many others. As an example, genetic algorithm that is a biologically inspired algorithm that mimics the survival of the fittest is widely used for optimization of mathematical functions [Drezner and Drezner, 2005]. One can view nature as a giant laboratory at which trial and error experiments are continually taking place and the successful results are implemented, self-maintained and continuing to evolve as changing challenges are addressed. In "executing' these experiment nature involves all the principles of science and engineering and they include the fields of physics, chemistry, mechanical engineering, materials science, and many others. The results are stored in the species genes and it takes place on all life scales from as small as virus to as large as elephants and whales. Failed experiments involve extension of the specific species as the case of the dinosaurs that has been a sustainable life form.

Our natural human form and behavior have always been fascinating to us and it led to their being a subject of extensive interest related to art, literature, and science. Increasingly, it is feasible to create lifelike robots that have human characteristics [Bar-Cohen and Breazeal, 2003; Bar-Cohen and Hanson 2009] using advances in materials, artificial intelligence, speech synthesis, image and speech recognition and many other capabilities. The latest humanlike robots are increasingly more sociable as their ability to express emissions both verbally and facially [Breazeal, 2002; Bar-Cohen and Hanson 2009]. Also, there were significant advances in the ability to produce artificial features including artificial intelligence, skin, vision, hearing, muscles and others. Electroactive polymers (EAP), also known as artificial muscles [Bar-Cohen, 2004; Bar-Cohen, 2011] are enabling biologically inspired mechanisms that once were considered science fiction ideas. Robots with humanlike attributes are known by many names including; Humanoids, Androids, Automatons as well as many others [Bar-Cohen and Hanson 2009]. Depending on their degree of similarity to humans, the author has used the following terms to describe such robots:

- Humanoid – These are robots that mimic the general appearance of humans and so include a head, arms, and possibly legs and eyes. Humanoids have a mechanistic likeness to humans; for example, in many instances the head may be shaped as a helmet, and thus may have neither the form nor features of a natural human head. Making such robots is easier than exactly copying the external human form.
- Humanlike Robots – These are designed to appear akin to real humans and so great efforts are made to exactly copy the human appearance and performance. The majority of roboticists engaged in this activity are based in Japan, Korea and China, with a few in the USA. Humanlike robots are more complex and most of the current ones are not commercially available but they have enormous potential since they offer greater ability to interact with people.

Historical Perspective

Robots are generally defined as electro-mechanical machines that look similar to humans and are able to perform complex tasks. The robot was derived from the Czech word *robota* that means compulsory labor and was first used in the 1921 play *Rossum's Universal Robots* by Karel Čapek. Prior to the invention of motors, moving joints of humanlike figures was done by strings, and such figures are known as marionettes. Even though they don't meet the definition of an electromechanical machine they can be considered a precursor to robots. Marionettes originated in France in medieval times and were adapted to box, curtain and black light theatres. Leonardo da Vinci is attributed to be the first person who, approximately in 1495, made a sketch for the production of a humanlike machine [Rosheim, 1996]. The French engineer, Jacques de Vaucanson, is recorded as the first producer of a physical machine that appears and acts like a human. He produced in 1737 the "Flute Player", which is a life sized mechanical figure that played a flute.

The development of digital computers made the most important contribution to the emergence of "smart" robots and the first recorded one is the 1946 ENIAC computer [McCartney 1999]. Today, high-speed, powerful microprocessors are used to control the operation of robots [Menzel and D'Aluisio, 2000]. The concept of machines that "think and learn" first documented in [Turing 1950] and later became known as 'Artificial Intelligence'. Other capabilities that are developed to produce lifelike robots include humanlike materials; actuators to emulate muscles as well as sensors for vision and hearing.

Robotic products are currently being used in entertainment, education, healthcare, military and many other fields. Robotics researchers are also increasingly collaborating with artists to make their robots appear more believable.

The components of a humanlike robot

The task of making a humanlike robot is complex and requires copying the human appearance and capabilities as well the social aspects of communicating emotions and possibly thoughts [Bar-Cohen and Breazeal, 2003; Bar-Cohen and Hanson, 2009]. It requires powerful actuators; sensors (vision, hearing, smell, position, force, texture and temperature); lightweight and multifunctional materials; and power source with reasonable operation duration. It requires such disciplines as; electro-mechanical engineering, materials science, and artificial intelligence. The head is a very important part of the appearance providing the identity of the robot. It is generally equipped with audio and visual sensors to monitor the interaction with humans and adjacent objects. To help making the robot appear humanlike, it is essential to cover it with a skin that is highly elastic without taking on residual deformation, and the Frubber (**Figure 1**) is an example of such a material [Hanson 2004]. The hands, arms and legs of humanlike robots are made to perform similar functions like natural appendages [Raibert, 1986].

Figure 1: Using Frubber, an artificial skin, a humanlike head that makes facial expressions was produced as a platform for testing artificial muscles. Made by David Hanson, Hanson Robotics, and photographed at JPL by the author.

The function of muscles is emulated by actuators and they move all the mechanically active parts and mechanisms. Natural muscles are both compliant and linear in behavior [Full and Meijer, 2004] and emulating them is important since they address key control requirements for making robots more lifelike. The actuators that are closest to emulate natural muscle are the electroactive polymers (EAP) and for their performance similarity they became known as "artificial muscles" [Bar-Cohen, 2004; Bar-Cohen 2011]. Many of the EAP materials known today emerged in the 1990s, but they are still weak in terms of their ability to perform significant mechanical tasks such as lifting heavy objects.

Artificial intelligence provides humanlike robots that control capabilities allowing them knowledge capture, representation and reasoning, planning, vision, face and feature tracking, language processing, mapping and navigation, natural language processing, and machine learning [Russell and Norvig, 2003]. Even though AI research has led to enormous successes in smart computer-controlled systems, their capability is still far from those of human intelligence.

Current and potential humanlike robots

Humanlike robots are now capable of performing impressive functions and are more lifelike than ever. However, while science fiction depicts them with superhuman abilities they are very far from reaching these levels of performance. Some of the developed capabilities include self-learning and periodic updates as well as autonomous operation and self-diagnostics. Given the limitation of current AI capabilities, there are robots that are controlled remotely by a human operator in a process termed ‘tele-operation’ or telepresence. One such robot is the Robonaut (i.e. robotic astronaut), which is being developed at NASA Johnson Space Center (JSC), Houston, Texas, USA. It first generation was made to mirror the movements of the upper body of a human operator who wears a control suit equipped with sensors. An example of the Robonaut performing a task is shown in Error! Reference source not found.. One may envision many potential possibilities of operating in telepresence where an expert can perform tasks at remote sites without having to leave his/her home or office. These tasks may include performing medical surgery or even conduct hazardous operations in extreme conditions without risk or to perform the task at a remote location without the need to travel. The closest to this capability is the remote operation of computers via the internet while telepresence allows performing physical tasks. In its second generation, efforts are made to develop an autonomous robot and currently it is being developed jointly with the the car manufacturer General Motors (GM) to allow it to operate alongside humans in manufacturing production lines.

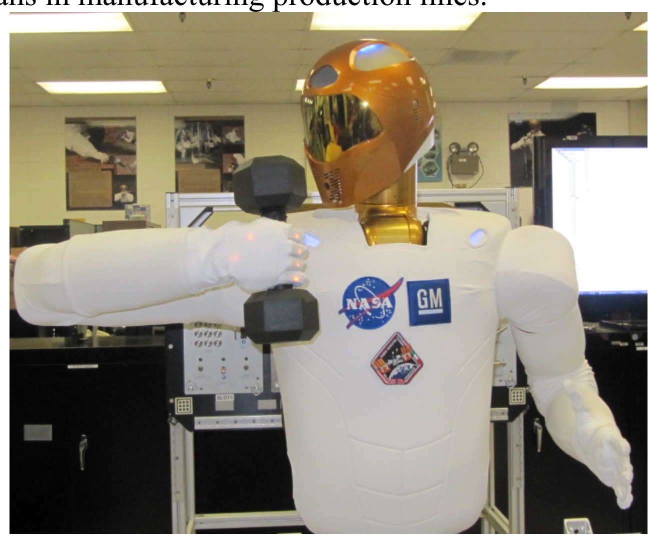

Figure 2: The Robonaut originally was developed as a teleoperated robot but the one shown in the photo is being developed as an autonomous robot.

Becoming our peers, or function as a useful part of our households, humanlike robots will need to be able to perform valuable daily tasks including; cleaning, repairs and household maintenance as well as possibly safeguarding the house and its perimeter. These tasks are quite complex and while humanlike robots can perform parts of them they will need much greater capabilities to be able to perform them fully autonomously. Significant efforts are currently being made to allow such capabilities. Robots have been developed in Japan and the USA to assist recovering patients, elderly people and others who need physical or emotional support [Bar-Cohen and Hanson, 2009].

Robots with the ability to interact with people and communicate emotionally are currently being considered for use in various therapies including treatment for patients with phobias, such as fear of speaking in public, and to improve peoples' communication skills. Humanlike robots are already showing promise in treating children with autism, by stimulating human's communication and interaction skills and so reducing the severity of this disorder [Fornia et al, 2007]. Additionally, robots may be used to help children develop social skills and aiding them with their understanding of body language. Humanlike robots may be widely used in education and therapy to provide realistic simulations under controlled conditions.

Concern of Humanlike Robots

Increasingly, humanlike robots are causing rise to ethical concerns, and could prove to complicate our lives, if, for example, they are programmed to deliberately cause harm, or take part in criminal activities. Operating robots in close proximity to humans requires safety measures to assure that humans are protected from harm and there have already been recorded incidents of humans been accidently killed by robots [Zinn et al., 2004].

As humanlike robots are being more capable they are expected to become household appliances, or perhaps even human peers; they may replace unskilled human labor, or possibly perform difficult and complex tasks in hazardous conditions. However, this may lead to concerns, fear and dislike of such robots [Bar-Cohen and Hanson 2009]. The Japanese roboticist Masahiro Mori [1970] hypothesized that as the similarity increases there will be initial enthusiasm, but it will turn into strong rejection and dislike, until the likeness becomes very close and then they will become more favored. Mori [1970] described this attitude graphically with a dip on a continuous curve and it became known as the Uncanny Valley hypothesis. The fear of humanlike robots may be related to sensitivity to behavioral anomalies that may indicate an illness. This may be attributed to our sensitivity to genetic disorders as part of our nature as living creatures and the survival of the fittest. This sensitivity raises an unconscious alarm of the potential impact on the gene pool. Critics do not accept this hypothesis as fact and they argue that it has never been proven by systematic experiment.

Challenges, Trend and Potential Development

Humanlike robots are being developed with impressive capabilities and appearance. Using AI, humanlike robots are making facial recognition and, some of the sophisticated ones, have personalized behavior that is different among the duplicates of the particular robot type. Also, there are robots that are able to walk or dance with great similarity to a real human. However, making robots significantly more capable involves many challenges that may be beyond the limits of the current state-of-the-art, and below there is a list of three 'simple' human capabilities that are challenge to make in robots. Every component of current humanlike robots will need to be improved before these robots are safe and functional enough to be truly a useful household appliance or a companion robot. Standardization of the hardware and software tools that are used to make robots may help advancing the field of humanlike robots allowing compatibility and interchangeability. In this way, scientists and engineers may be able to focus on making improvements in their own areas of specialization rather than having to be able to produce the complete system. Another issue that is important to the scientist and engineers who seek to develop new robots is the related cost, where the development of the sophisticated ones is quite prohibitive. Novel manufacturing methods may be useful as a stop gap approach until robots reach mass production levels that will inevitably bring their price down to affordable levels. A further concern is that of robot non-obedience and unacceptable behavior. Making a humanlike robot self-aware of its actions and having it operate with rules of right and wrong may be very challenging, and some claim impossible. As we get used to seeing humanlike robots as helpers and find them more useful in performing increasing number of critical tasks, the author believes that we will be more receptive to having them in our household.

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